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FRACTURE MECHANICS TESTS AND DEFECT CRITERIA FOR THE 120-MM M121 MORTAR BASEPLATE

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13. ABSTRACT *(Maximum 200 words)*

Calculations of firing stress at several locations of the 120-mm M121 mortar baseplate were made based on available strain gage data. Measurements of fracture toughness were performed for seven weld and heat-treat conditions of the 4130 steel used for the baseplate. Calculations were made of the ratio of applied K to the critical K for fracture for various combinations of firing stress and material condition. Based on the results of the tests and calculations, allowed defect criteria for the baseplate were recommended.

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FIRING STRESSES

The first step in any fracture mechanics analysis is determination of the applied stresses in the component. A finite element stress analysis of the baseplate is underway (by the Modeling and Simulation Branch of Benet Laboratories), and experimental measurements of firing stresses from strain gage data are also available (from the Infantry and Special Projects Branch). For the determination of interim defect criteria for the 120-mm M121 mortar baseplate in this report, the available experimental results will be used, and modified as required at a later time using the finite element results.

Table 1 summarizes radial direction firing stress results estimated from some of the strain gage results, at locations of prime interest for critical defect size calculations. The locations are indicated in Figure 1. Note in Figure 1 that strain gage data were obtained on the inner trunk (in close proximity to the socket, where firing loads are applied), on the outer trunk, and near the outer edge of the plate. The gages on the side associated with the firing direction are (for the purposes here) the forward gages, and those opposite are the rear gages. Data are shown in Table 1 for zone 13 and zone 10 firings and for both center firing, where the firing direction is centered on one of the baseplate legs, and for firing to the sides, both max left and max right. Note in the table that the forward gages give tensile stresses, as would be expected due to the reaction force from firing. Likewise, the rear gages are predominantly compressive.

Table 1. Peak Firing Stress Estimated from Strain Gage Data

Firing Conditions	Location	Forward Gages Stress (MPa)	Rear Gages Stress (MPa)
ZN13-Center	Inner Trunk	+280	-930
	Outer Trunk	+60	+70
	Outer Edge	+80	-110
ZN10-Center	Inner Trunk	+80	-390
ZN10-Sides	Inner Trunk	+200	-630

The important information from Table 1 related to defect criteria are the maximum radial tensile stress, 280 MPa (41 Ksi), at the inner cone and the maximum radial tensile stress elsewhere in the baseplate, 80 MPa (12 Ksi). These values will be used in the upcoming fracture calculations. Also needed for the calculations are values of fracture toughness, discussed next.

FRACTURE TOUGHNESS MEASUREMENTS

Measurements of fracture toughness were performed for seven weld and heat-treat conditions of the 4130 steel used for the baseplate. The J-integral method of elastic-plastic fracture toughness testing was used, as described in recent work (ref 1). Table 2 lists the conditions tested and the results. Note the significantly lower fracture toughness for the heat-affected zone, as-welded condition. It is very important to note that this condition also displayed a brittle cleavage failure in the fracture tests. Since a cleavage failure occurred in the room temperature, slowly-loaded laboratory tests, similar cleavage failures are certain to occur under firing conditions, since they always involve more rapid loading and can be at temperatures well below room temperature.

The load versus displacement plot of one of the two heat-affected zone, as-welded samples that failed by brittle cleavage is shown as the lower curve in Figure 2, along with the upper curve, a plot of a heat-affected zone, heat-treated sample. It is clear that the as-welded condition of the weld heat-affected zone has very poor fracture properties compared to the heat-treated condition. *Heat treatment of all welds is strongly recommended.*

Table 2. Measured Fracture Toughness from 4130 Baseplate Material

Material	Condition	Fracture Toughness (K_J; MPa$\sqrt{m}$)	Failure Behavior
Weld Metal	Heat Treated	220	Ductile
	As-Welded	270	Ductile
	Tempered	250	Ductile
Heat-Affected Zone	Heat Treated	260	Ductile
	As-Welded	60	Cleavage
	Tempered	230	Ductile
Plate; Longitudinal	Heat Treated	230	Ductile
Plate; Transverse	Heat Treated	190	Ductile

APPLIED K FOR FRACTURE

The value of applied stress intensity for various loading and crack sizes of the baseplate can be calculated from the expression for the stress intensity factor, K, for a crack of length 2a in a tensile-loaded panel with remote stress, S_t (ref 2)

$$K_{APPLIED} = S_t (\pi a)^{1/2} \qquad (1)$$

Using Equation (1), the tensile firing stress values from Table 1, and the measured fracture toughness values from Table 2, a ratio of the applied K to the critical value for fracture (the fracture toughness, K_J) can be calculated for a range of assumed crack lengths, as shown in Table 3. It is clear from the results in the table that the as-welded heat-affected zone condition is the most critical. For the higher of the firing stresses, 280 MPa, corresponding to welds of the inner trunk, the ratio $K_{APPLIED}/K_J$ exceeds 1 for crack lengths of 15 mm or longer, and this takes no account of uncertainties in any of the experimental or analytical modeling.

Table 3. Ratio of Applied K to Fracture Toughness for 4130 Baseplate

Material/ Condition	Firing Stress (MPa)	Ratio of $K_{Applied}/K_J$				
		a = 2 mm	a = 5 mm	10 mm	20 mm	50 mm
Weld Metal:						
All Conditions	S_t = 80	0.03	0.05	0.06	0.09	0.14
	S_t = 280	0.10	0.17	0.23	0.32	0.50
Heat-Affected Zone:						
Heat Treated	S_t = 80	0.02	0.04	0.05	0.08	0.12
	S_t = 280	0.09	0.14	0.19	0.27	0.43
As-Welded	S_t = 80	0.11	0.17	0.24	0.34	0.53
	S_t = 280	0.37	0.58	0.83	1.20	1.90
Tempered	S_t = 80	0.03	0.04	0.06	0.09	0.14
	S_t = 280	0.10	0.15	0.22	0.30	0.48
Plate:						
Both Conditions	S_t = 80	0.03	0.05	0.08	0.11	0.18
	S_t = 80	0.12	0.18	0.26	0.37	0.58

RECOMMENDATIONS

Allowed Defect Criteria

The allowed defect criteria in Table 4 are recommended for the 120-mm baseplate as a replacement of the current criteria given in Note 11 of the baseplate print, part number 12576881. The basis for these criteria was that the ratio $K_{APPLIED}/K_J$ be one-third or lower. Note that for the as-welded condition on the critical inner trunk, the criterion is a 2-mm long allowed defect. Since it would be very difficult to be sure that this small a defect is not present, this criterion essentially requires that any defect on the inner trunk welds be either fully heat treated or tempered. As-welded repairs on the inner trunk are not allowed.

Table 4. Allowed Defect Criteria for Welds in the 120-mm Baseplate

	Heat-Treated or Tempered	As-Welded
Inner Trunk Welds; Part No. 12576901	20-mm Length	2-mm Length
All Other Welds	50-mm Length	50-mm Length

Additional Tests

If tests of 4130 steel welds in other conditions or tests of other materials are required, the type of analysis and calculations used here could easily be extended. The only new requirement would be the additional fracture toughness tests.

REFERENCES

1. J.H. Underwood, E.J. Troiano, and R.T. Abbott, "Simpler J_{Ic} Test and Data Analysis Procedures for High Strength Steels," *Fracture Mechanics: Twenty-Forth Symposium, ASTM STP 1207*, American Society for Testing and Materials, Philadelphia, 1994.

2. H. Tada, P.C. Paris, and G.R. Irwin, *The Stress Analysis of Cracks Handbook*, Del Research Corp., Hellertown, PA, 1973.

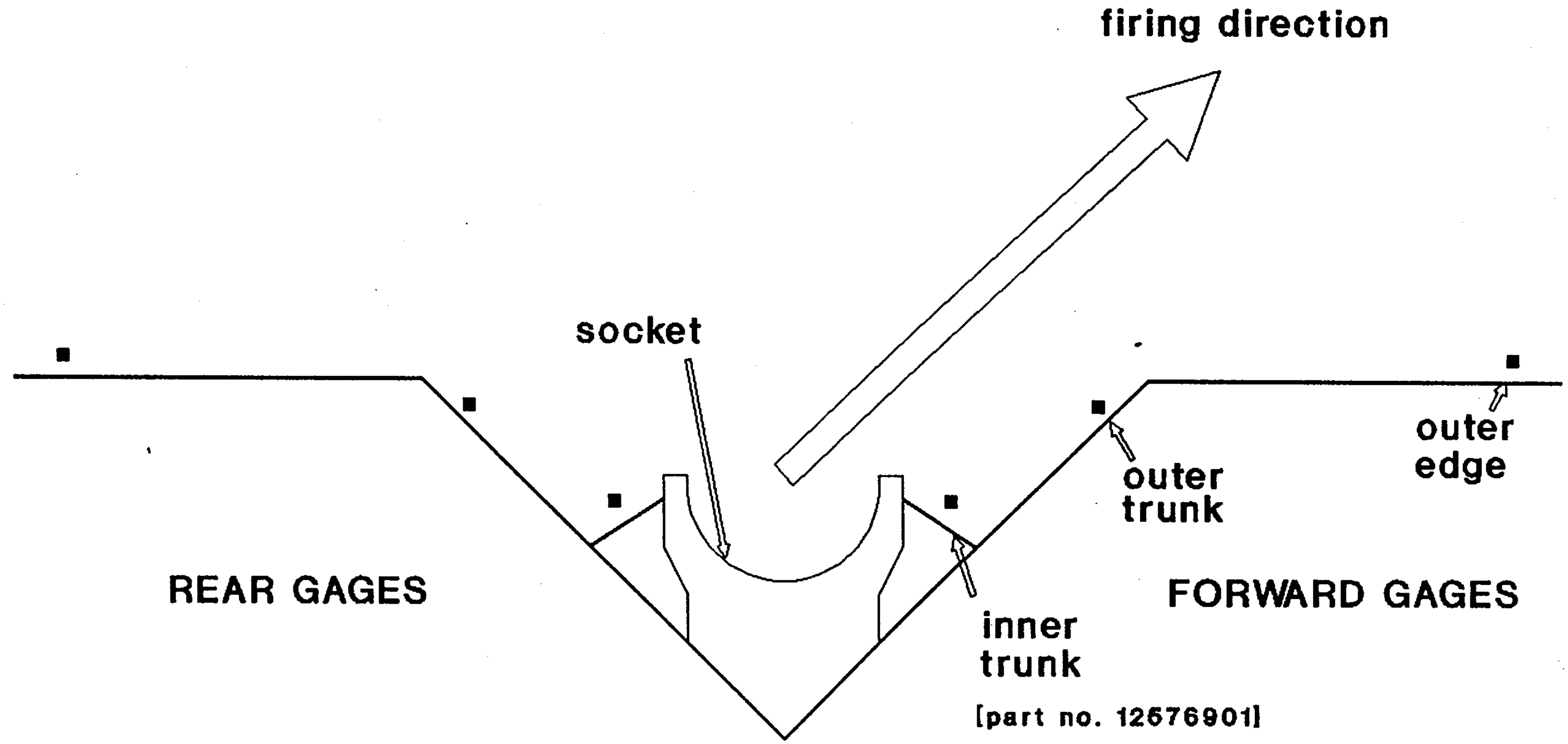
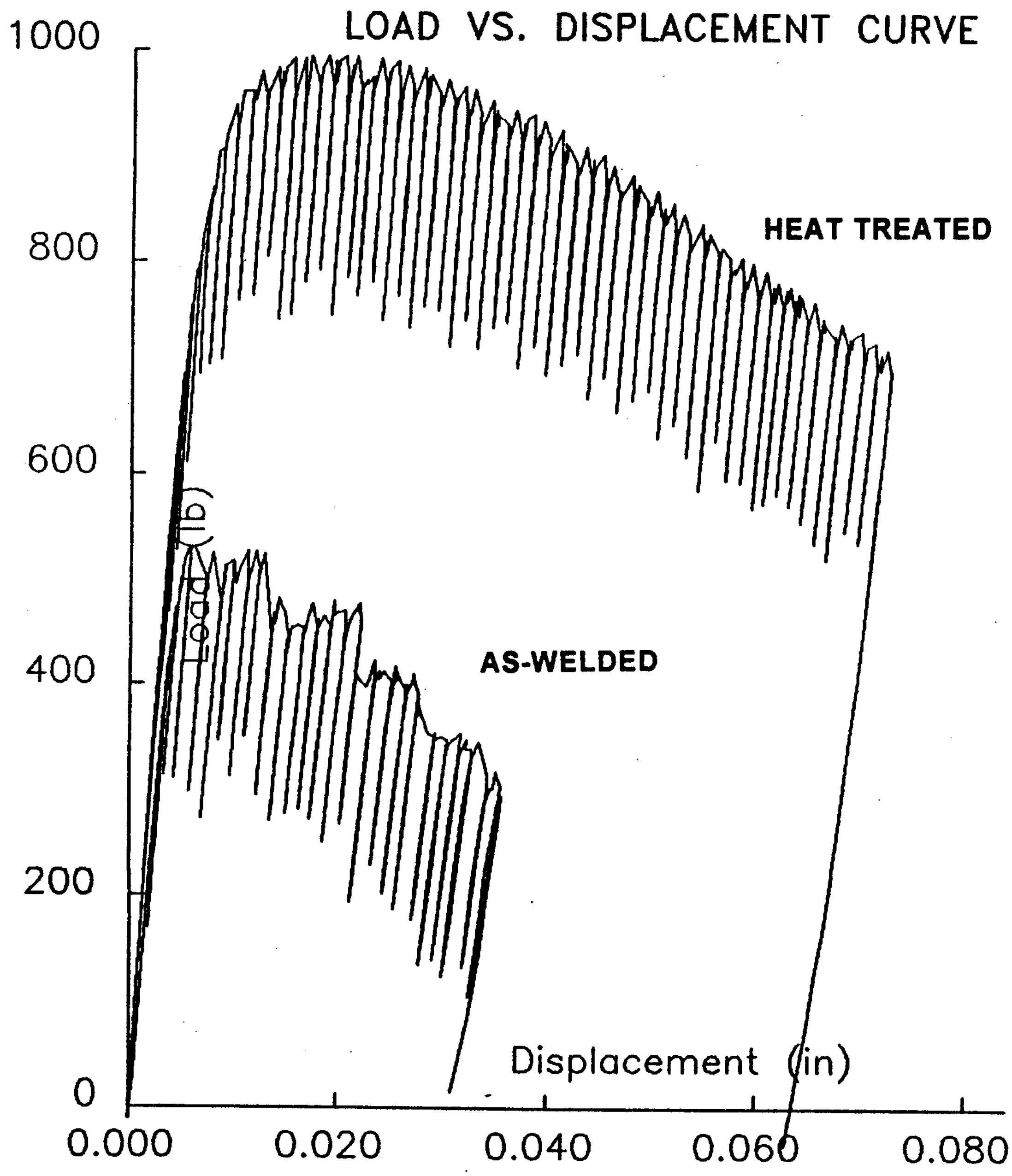


Figure 1 - Sketch of Baseplate

Figure 2


LOAD VS. DISPLACEMENT CURVE
1000
800
600
400
200
0
Load (lb)
HEAT TREATED
AS-WELDED
Displacement (in)
0.000
0.020
0.040
0.060
0.080

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